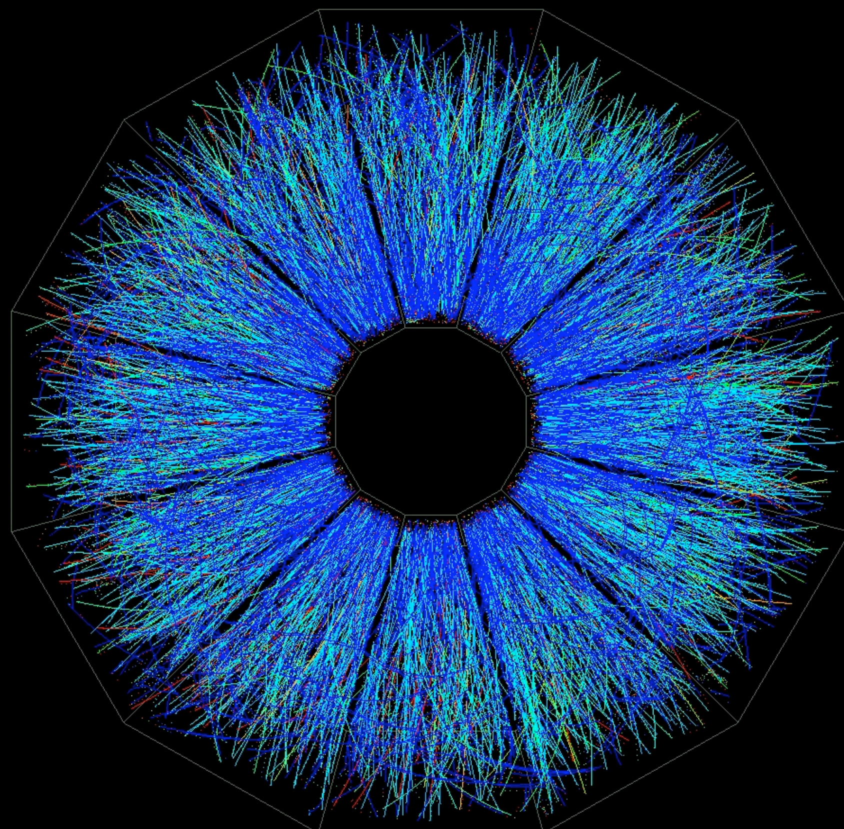
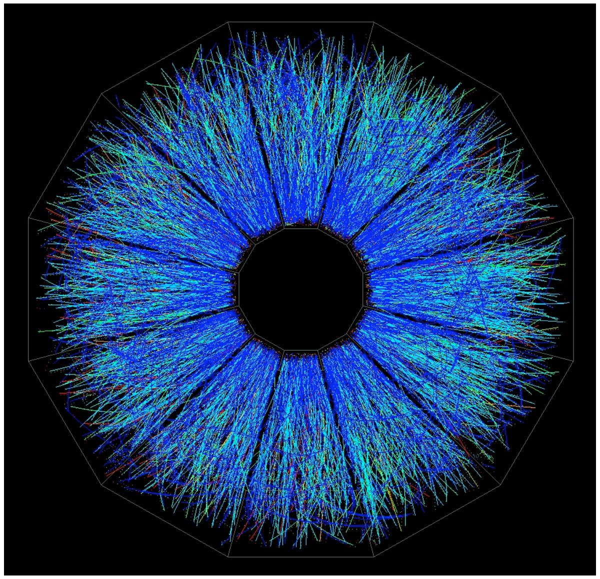
Bulk Particle Production
A Global View



Gunther Roland

Bulk Properties



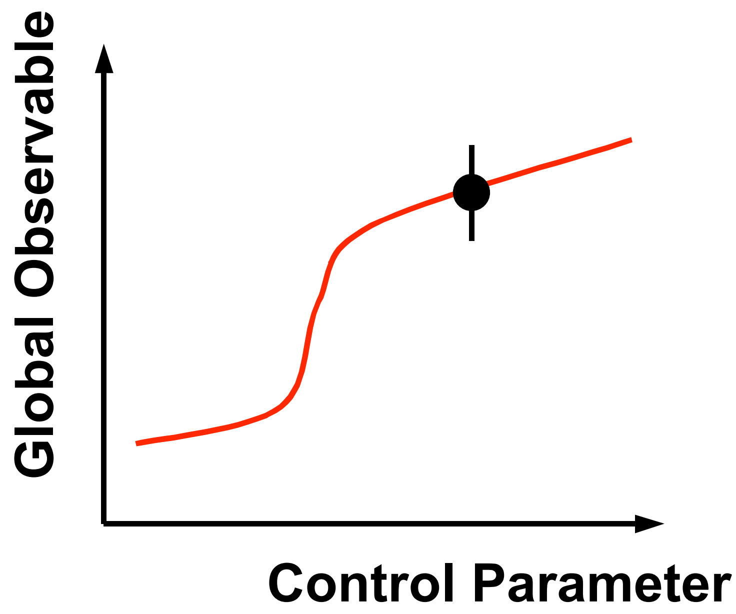
Single Au+Au Collision

O(10^4) 4-Vectors

How many (Parameters / Concepts) needed to describe *average* collision?

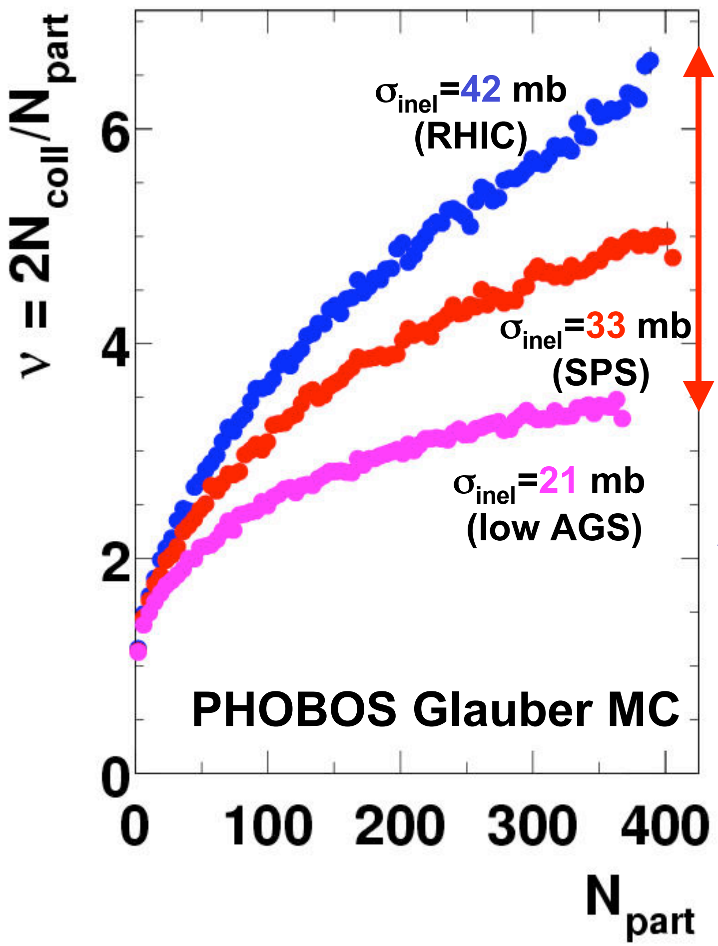
Provide background (5 - 15% accuracy) against which we can search for structure

Global Observables



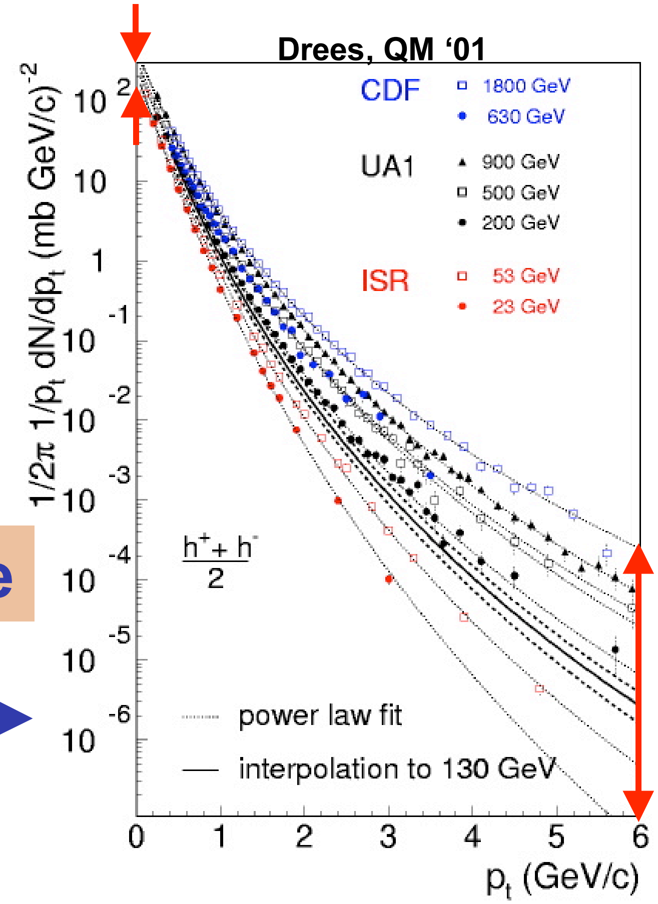
"Global Observables" need to be understood in context

Control Parameters



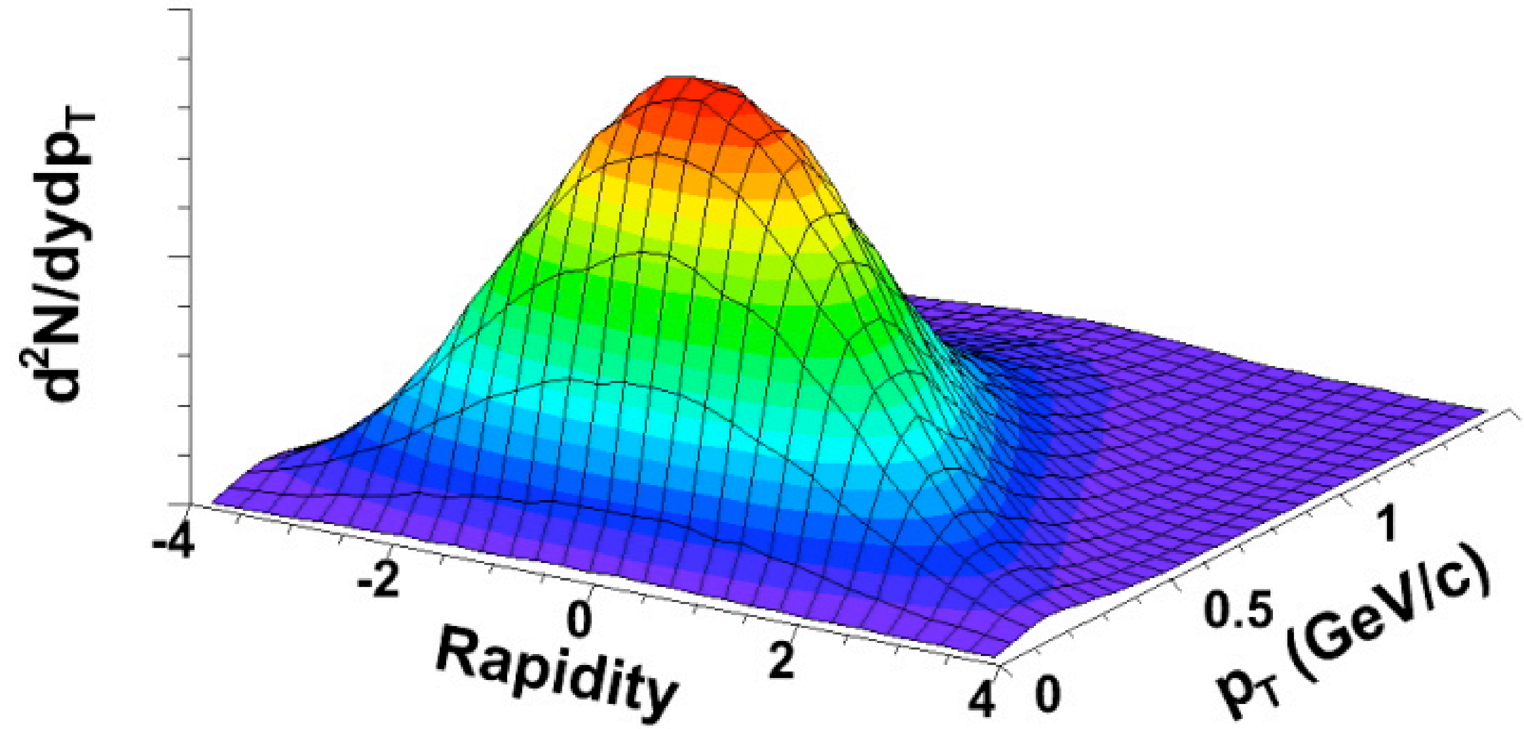
System-Size

Energy

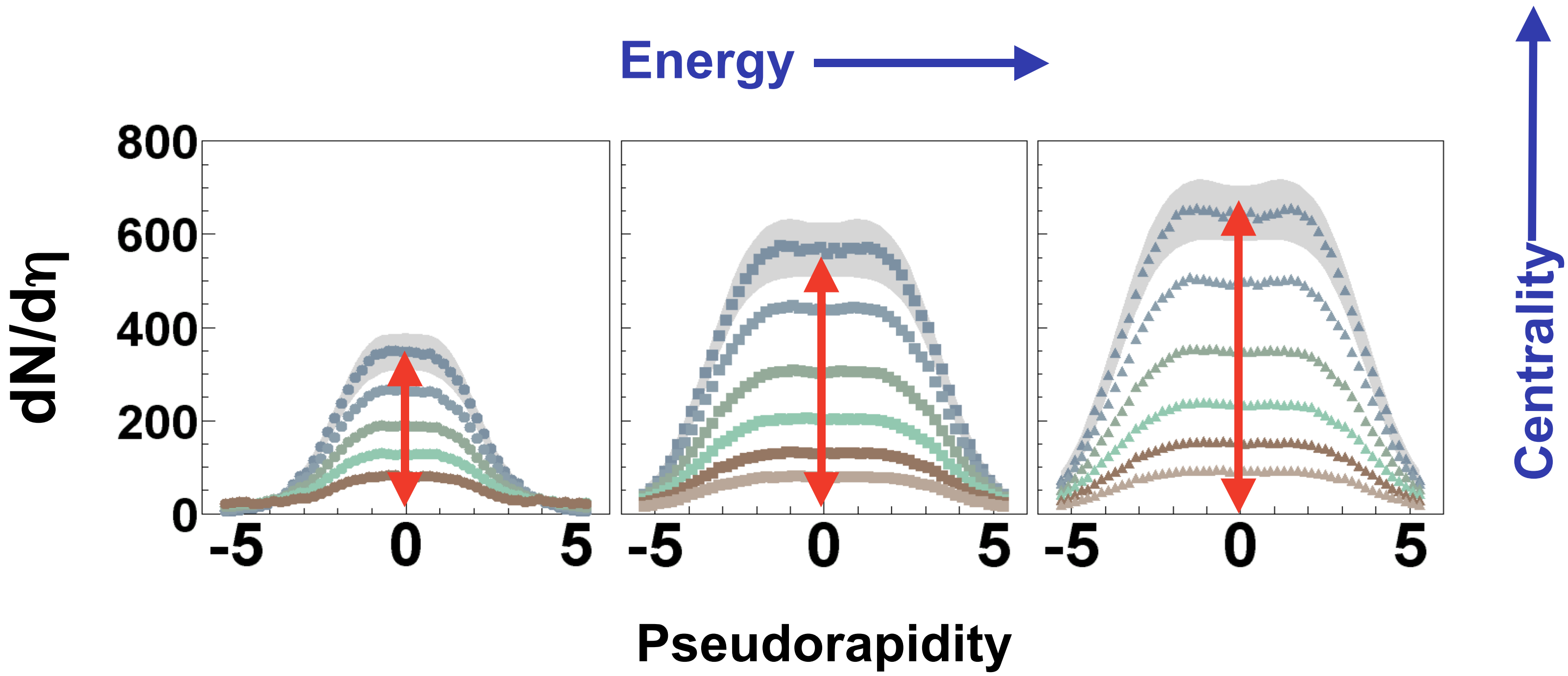


Also: Different systems (different nuclei, pp, pA, e^+e^-)

Bulk Properties



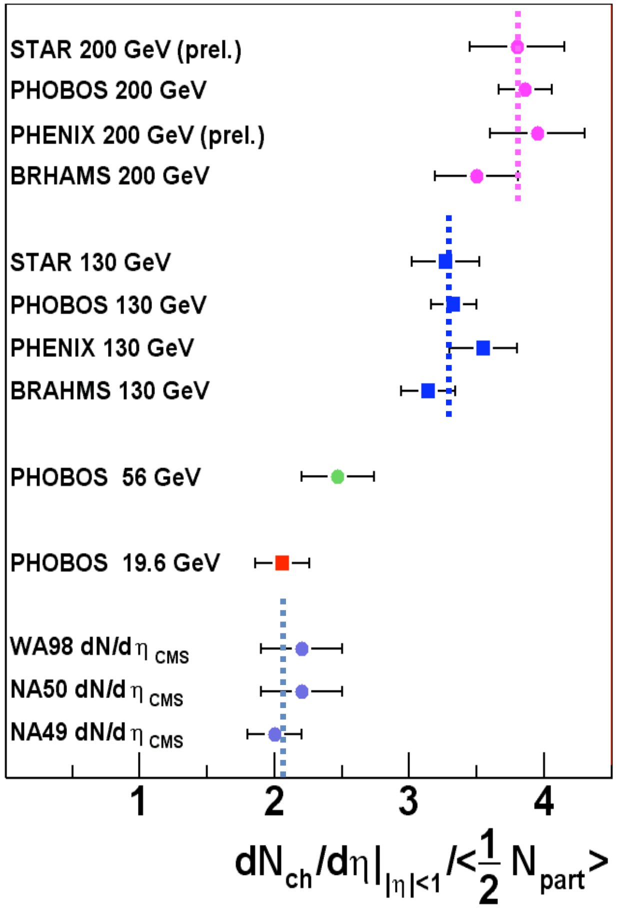
I. Particle Density near Mid-Rapidity



How does Density at 90° change with Energy and Centrality?

Please, see poster by Sasha Milow !

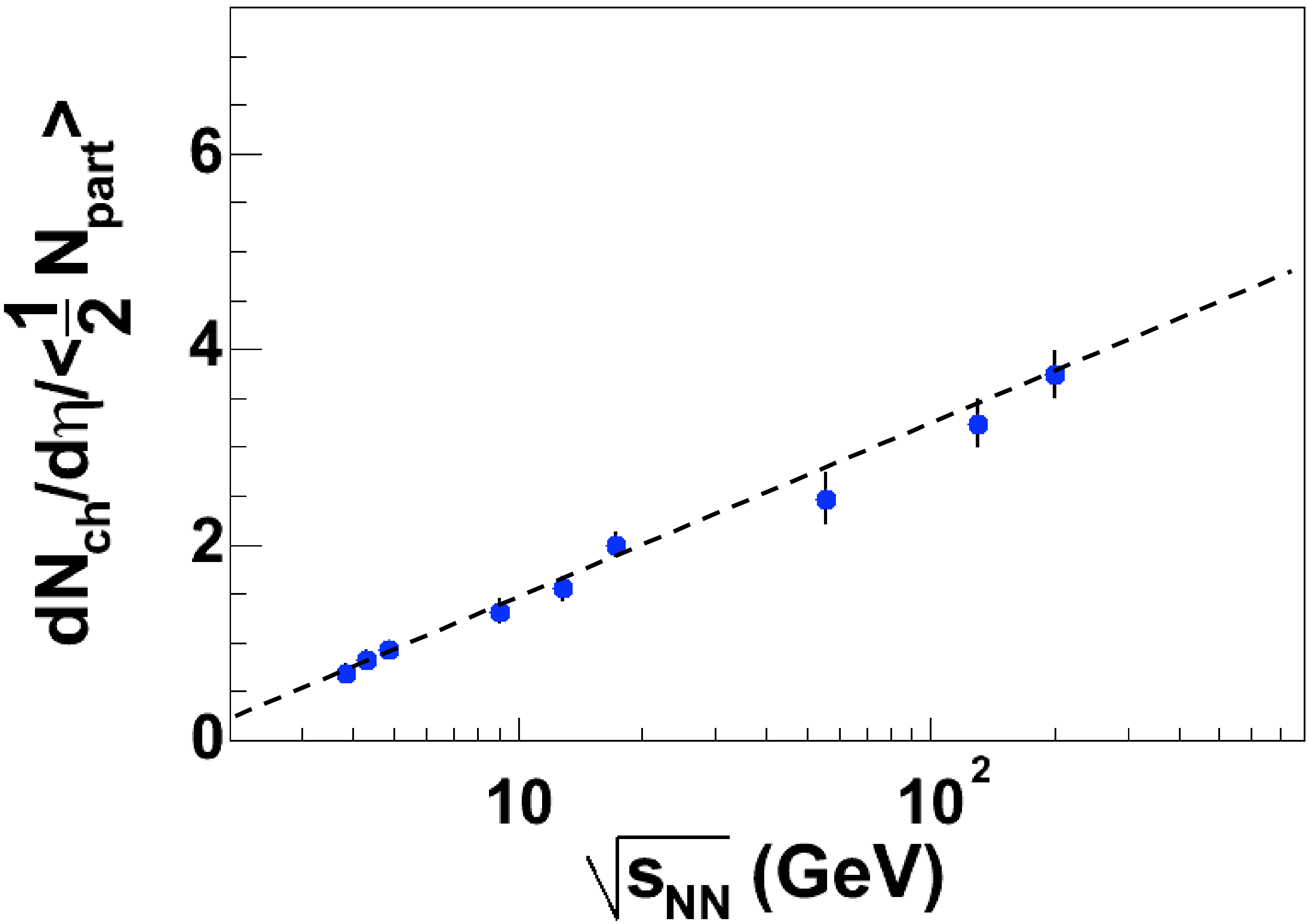
Particle Density near Mid-Rapidity



Beware of the Jacobian!

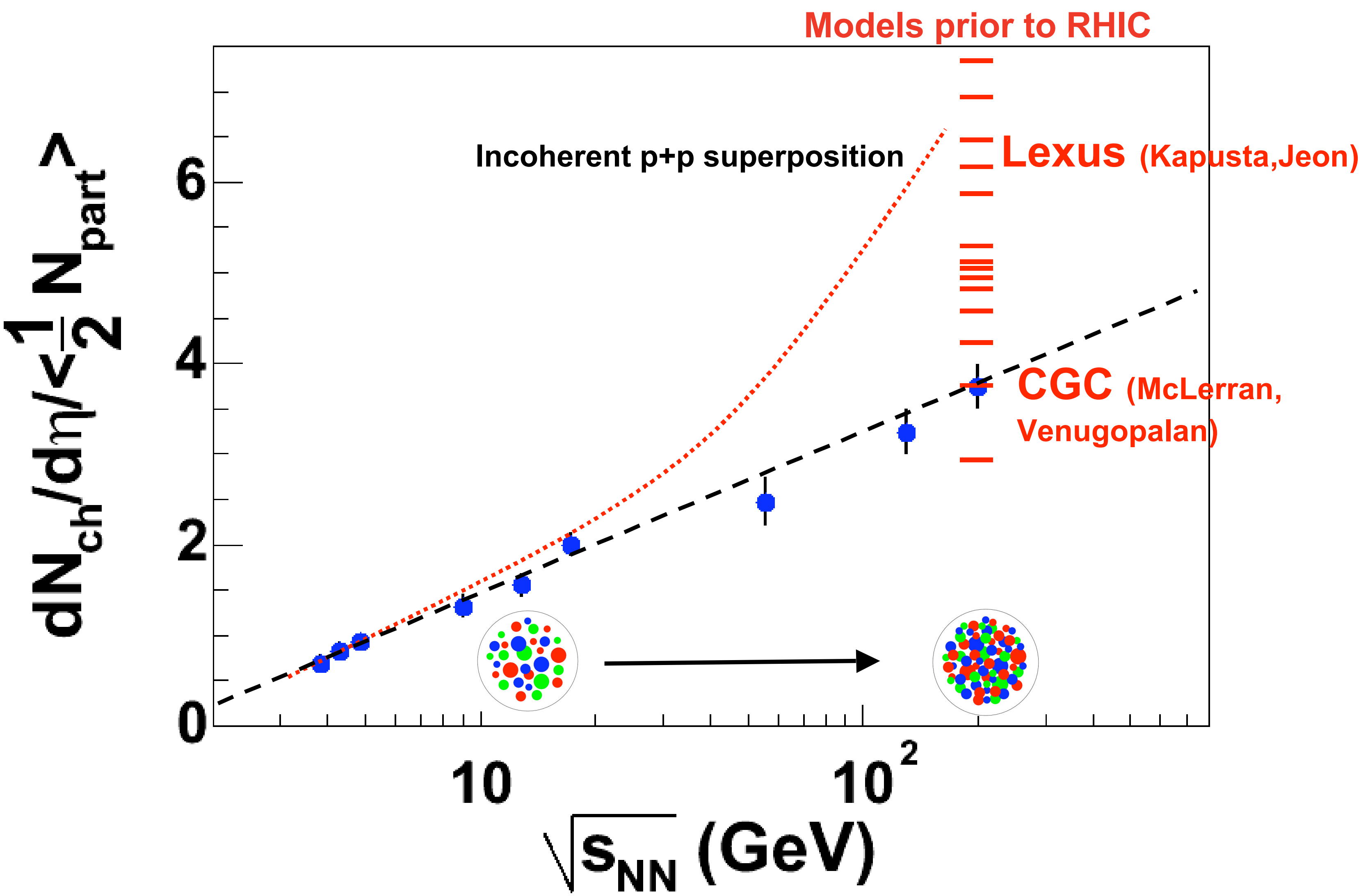
$$dN/d\eta = <\beta> dN/dy$$

Particle Density near Mid-Rapidity



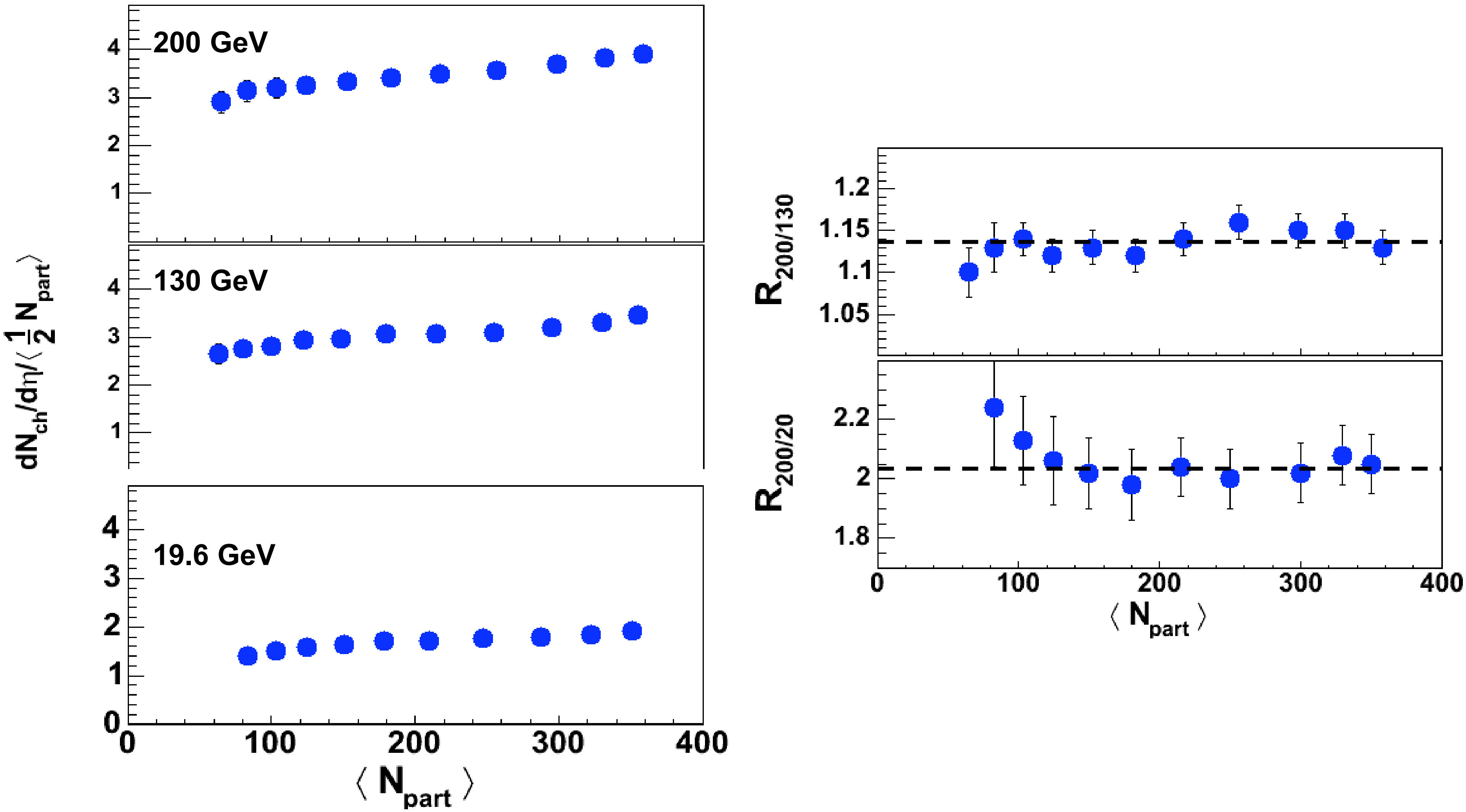
Logarithmic Rise with Collision Energy

Particle Density near Mid-Rapidity



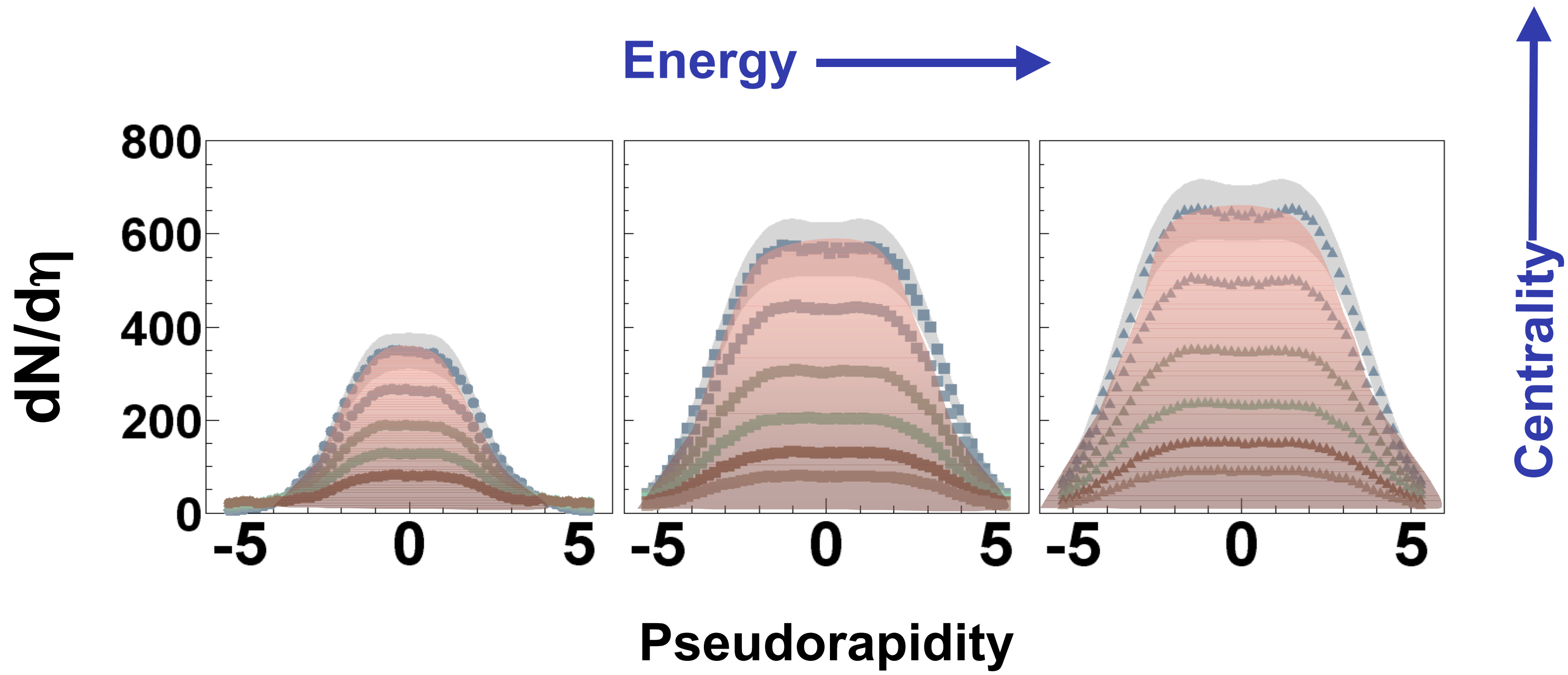
"Coherence" of Hardon Production

Centrality Dependence at |η| < 1



Surprising Lack of Energy Dependence

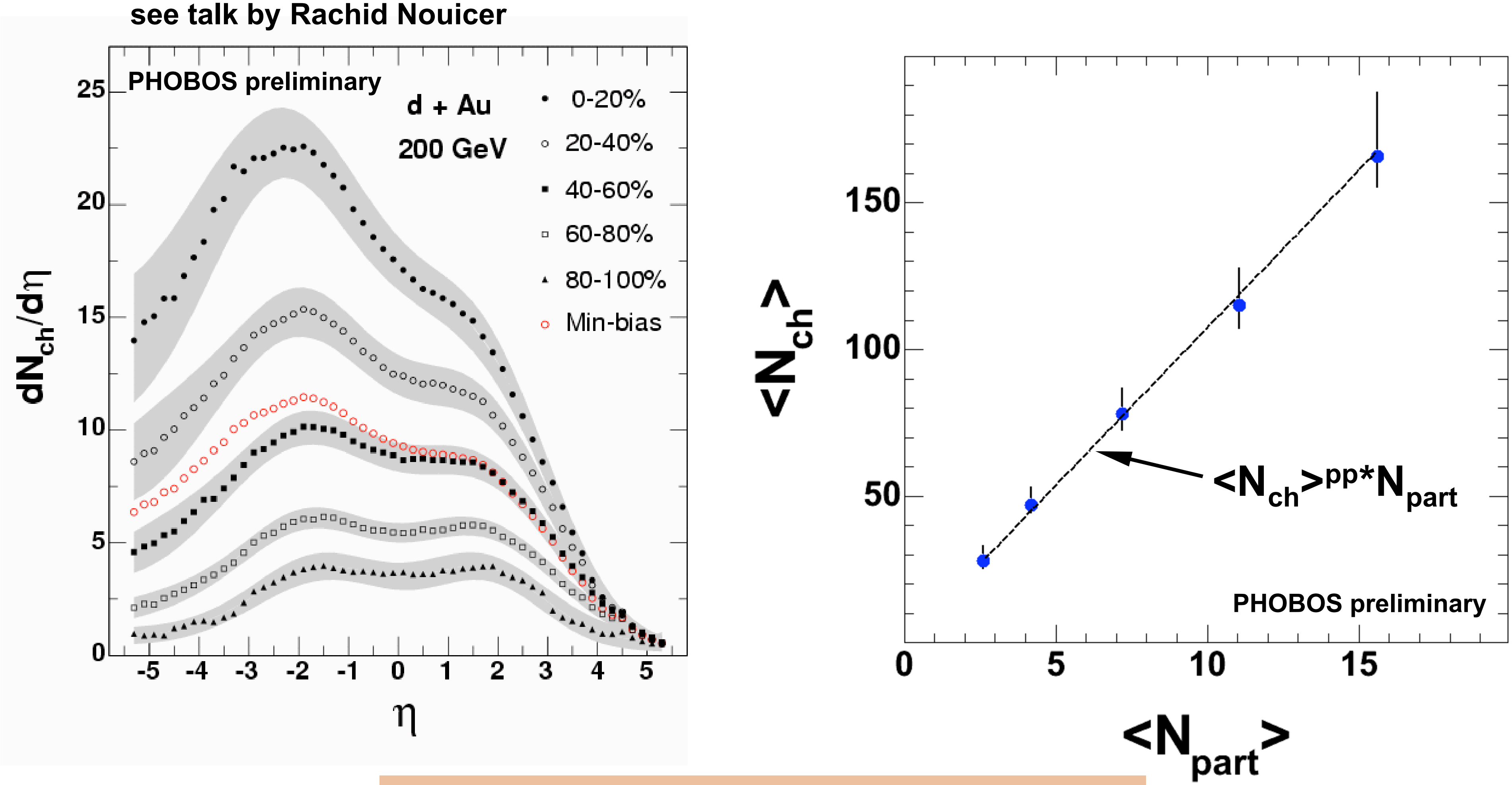
II. 4-π Multiplicity $\langle N_{ch} \rangle$



How does Integral over 4-π, $\langle N_{ch} \rangle$, change with Energy and Centrality?

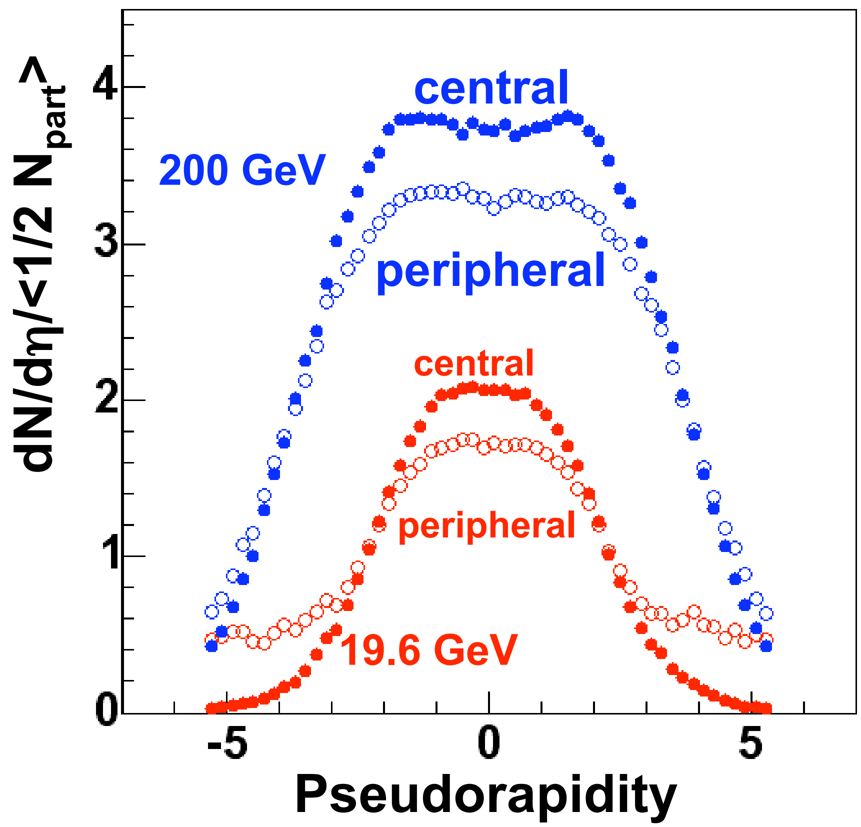
$\langle N_{ch} \rangle$ vs N_{part} in d+Au

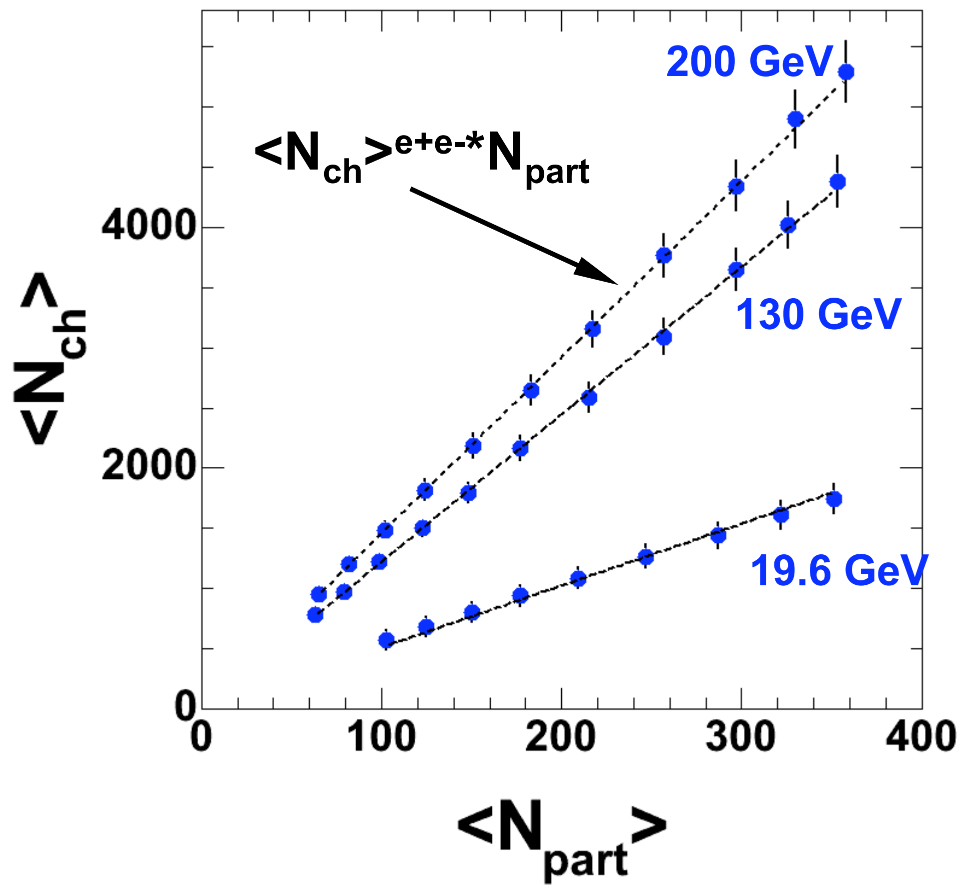
see talk by Rachid Nouicer



d+Au Multiplicity proportional to p+p Multiplicity * N_{part}

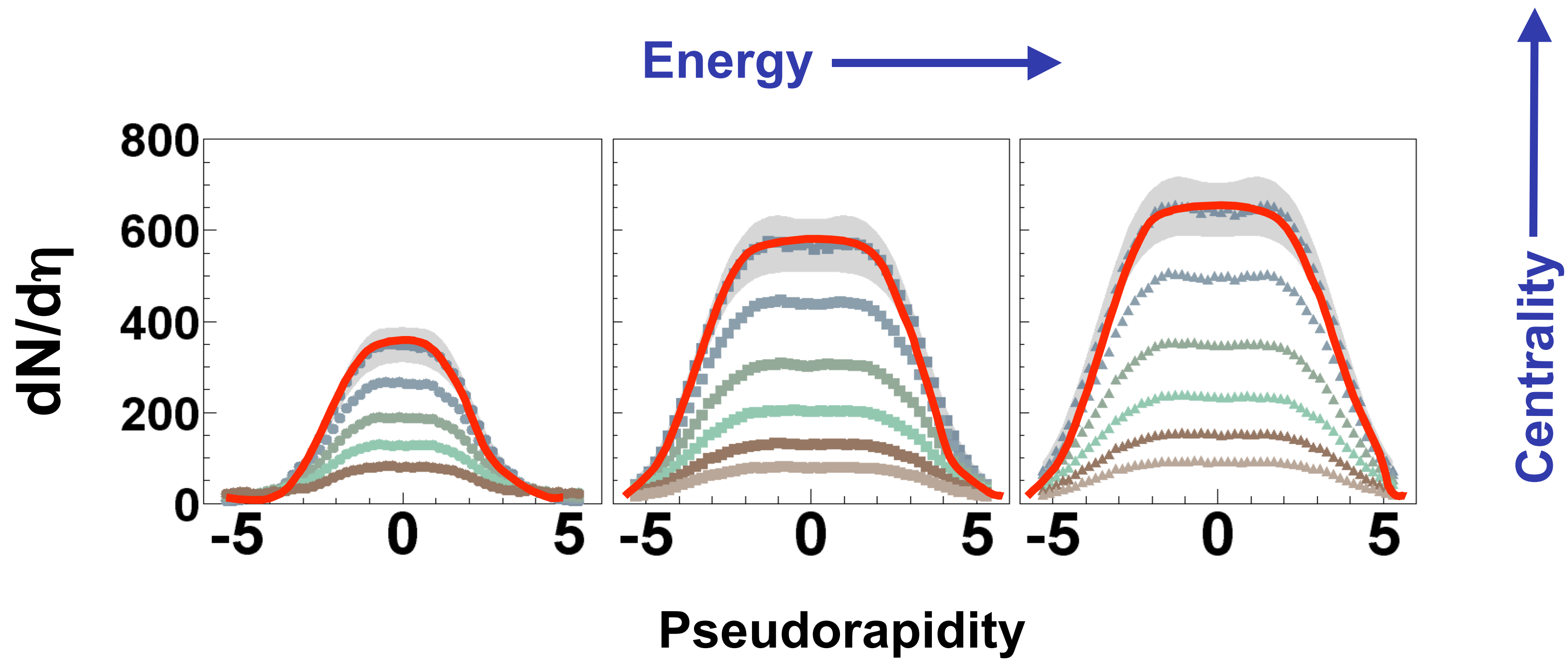
$\langle N_{ch} \rangle$ vs N_{part} in Au+Au





Au+Au Multiplicity proportional to N_{part}

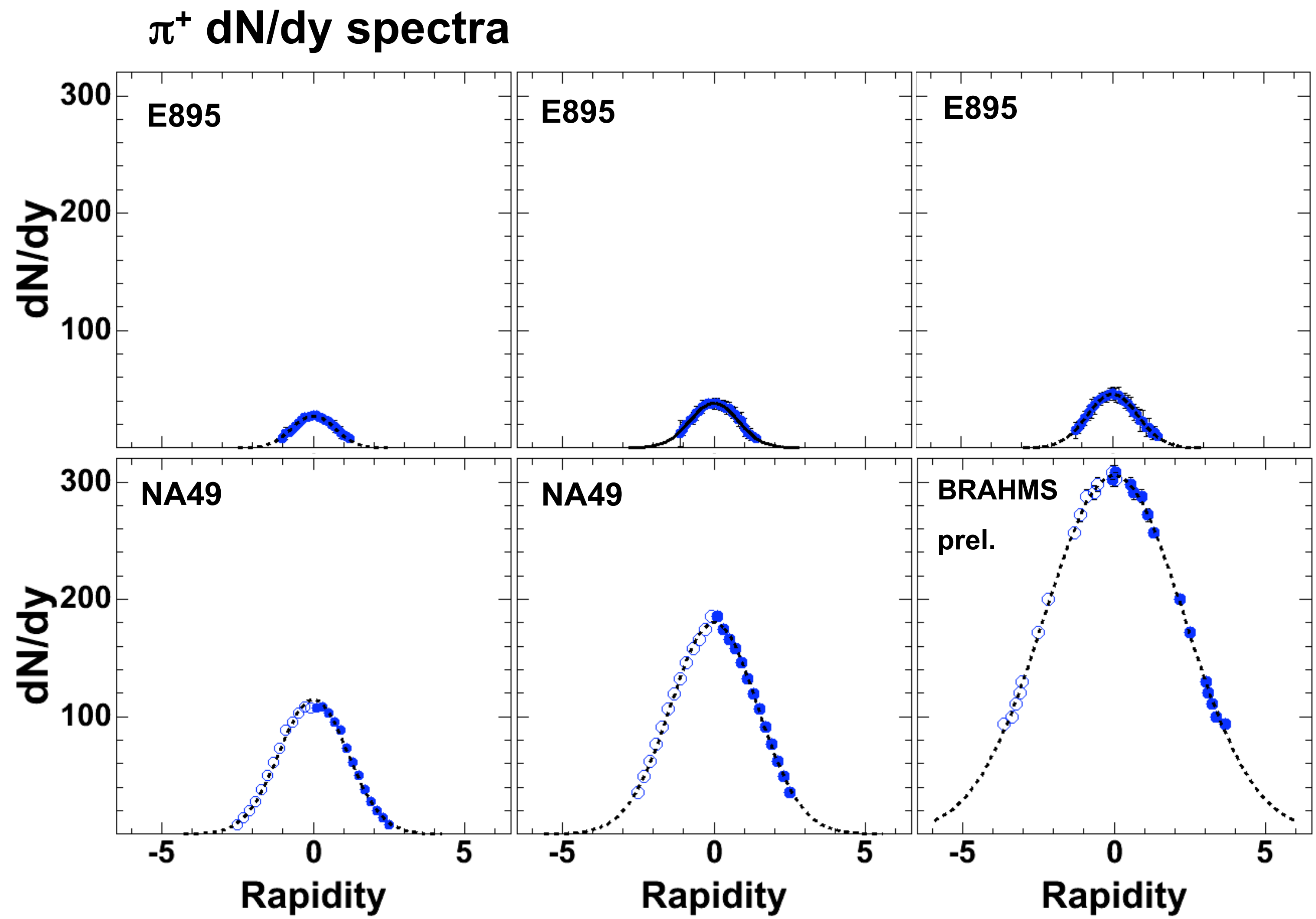
III. Shape of dN/dη Distributions



How does Shape of dN/dη (dN/dy) change with Energy?

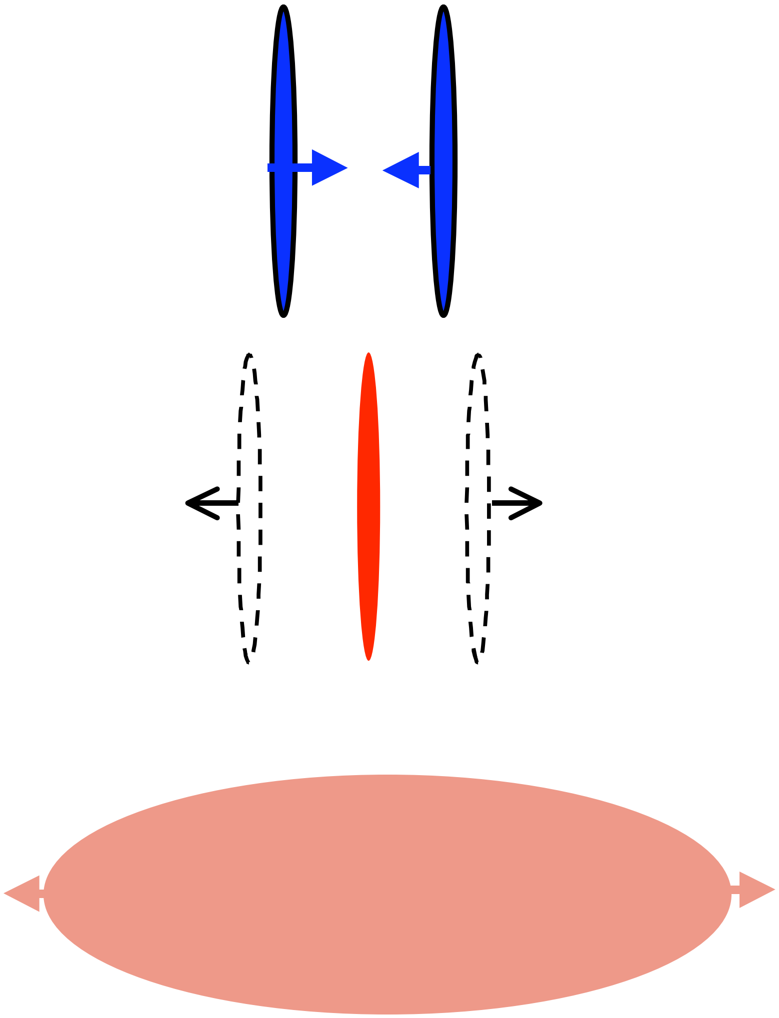
Reaching the Central Plateau?

Boost-invariance?



Single Gaussian fits from 2 to 200 GeV

Landau Hydrodynamics



Carruthers, Duong-Van on pp data in <u>1973</u>:

surprisingly well described by Landau's energy-dependent Gaussian rapidity distribution [see Eq. (2.1) for the definition of y]

$$\frac{1}{\sigma_{\text{in}}}\frac{d\sigma}{dy}=\frac{dN}{dy}$$

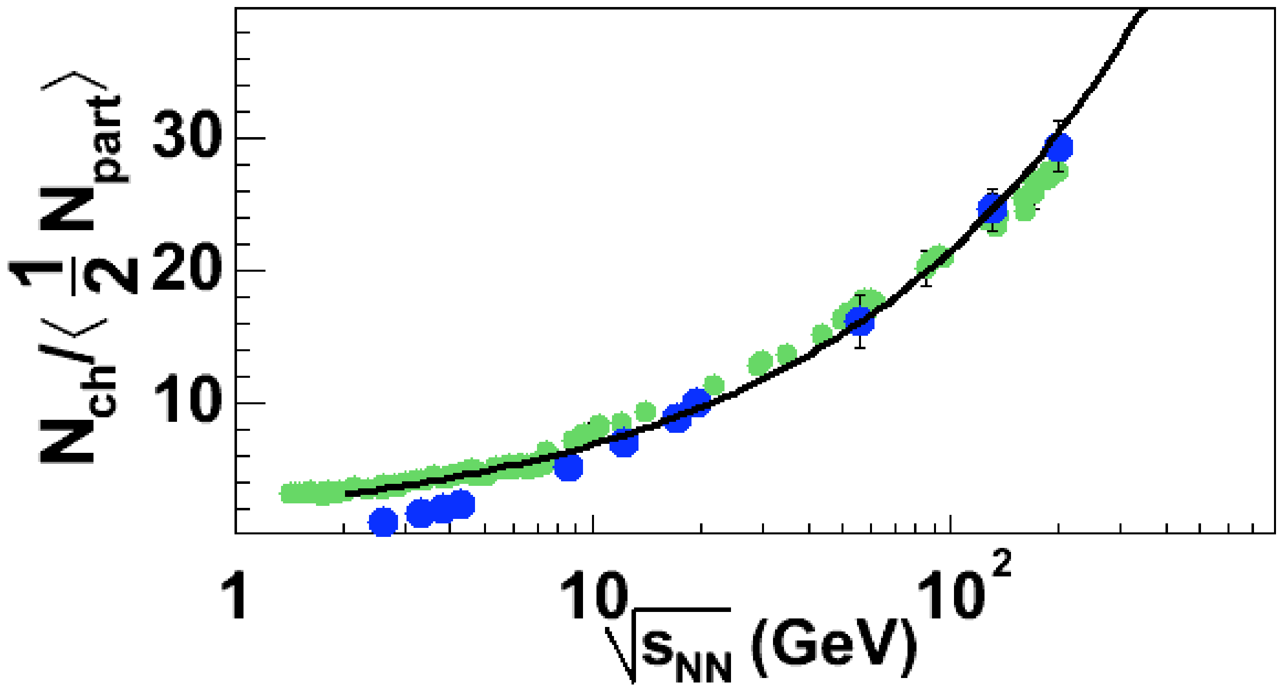
$$=N\exp(-y^2/2L)/(2\pi L)^{1/2}, \qquad (1.5)$$

where the parameter L is

$$\boxed{L=\tfrac{1}{2}\ln(s/4m_p{}^2),} \qquad (1.6)$$

where s is the squared total c.m. energy.

$\langle N_{ch} \rangle$ vs sqrt(s) revisited



Secondly, we wish to stress that as a function of *available energy* W_{had} the hadronic multiplicity varies as $N \approx 2.2\ W_{had}^{1/2}$ over a vast range of initial energies.[25]

Carruthers, Duong-Van on pp and e^+e^- data in 1983:

IV. Spectrum of Produced Hadrons

Temperature Chemical Potential

$$\langle n_j \rangle = \frac{(2J_j+1)V}{(2\pi)^3} \int \mathrm{d}^3\mathrm{p} \left[\mathrm{e}^{\sqrt{\mathrm{p}^2+m_j^2}/T + \boldsymbol{\mu}\cdot\mathbf{q}_j/T} \pm 1 \right]^{-1}$$

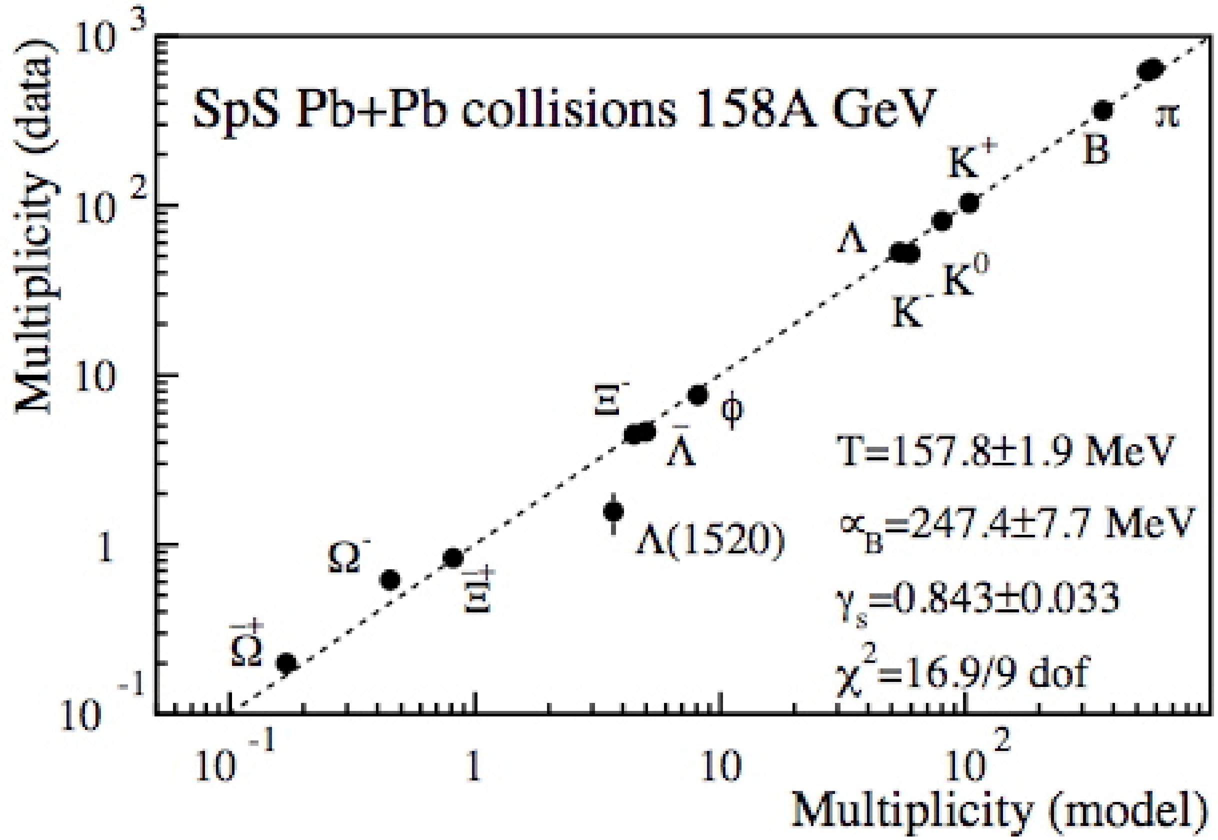
Yield Mass Quantum Numbers

Hagedorn, Becattini, Braun-Munzinger, Cleymans,

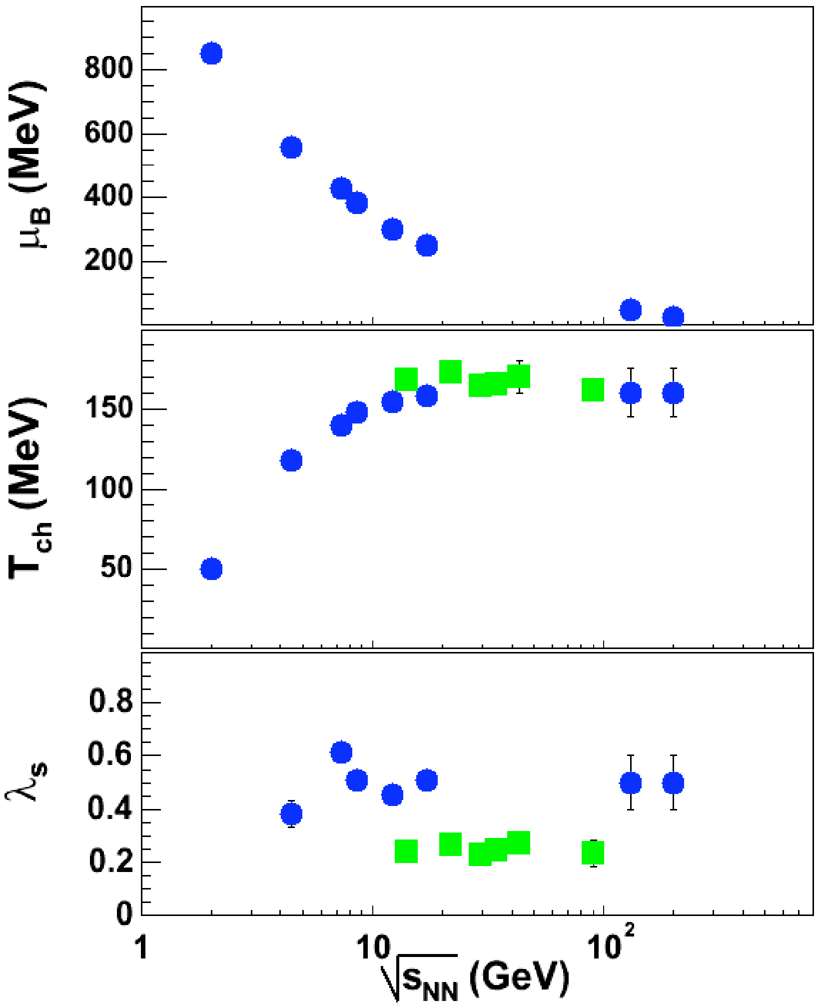
Letessier, Mekijan,Rafelski, Redlich,Stachel, Tounsi

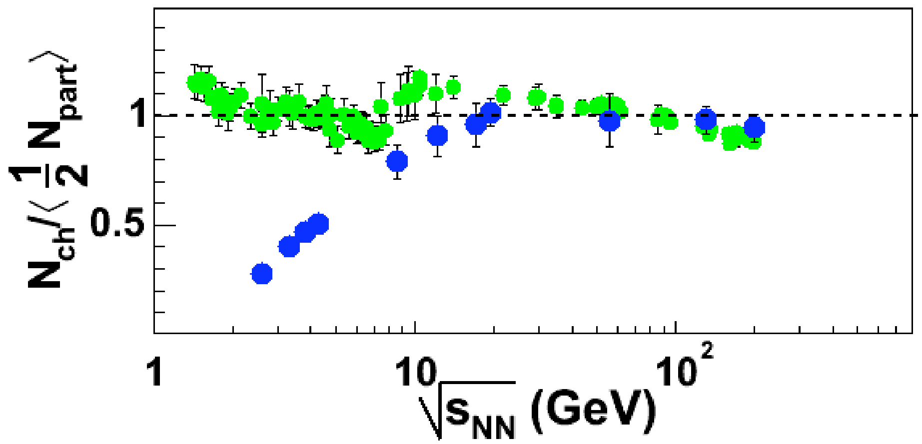
Spectrum of Produced Hadrons

$$\langle n_j \rangle = \frac{(2J_j+1)V}{(2\pi)^3} \int d^3p \left[e^{\sqrt{p^2+m_j^2}/T + \boldsymbol{\mu}\cdot\mathbf{q}_j/T} \pm 1 \right]^{-1}$$

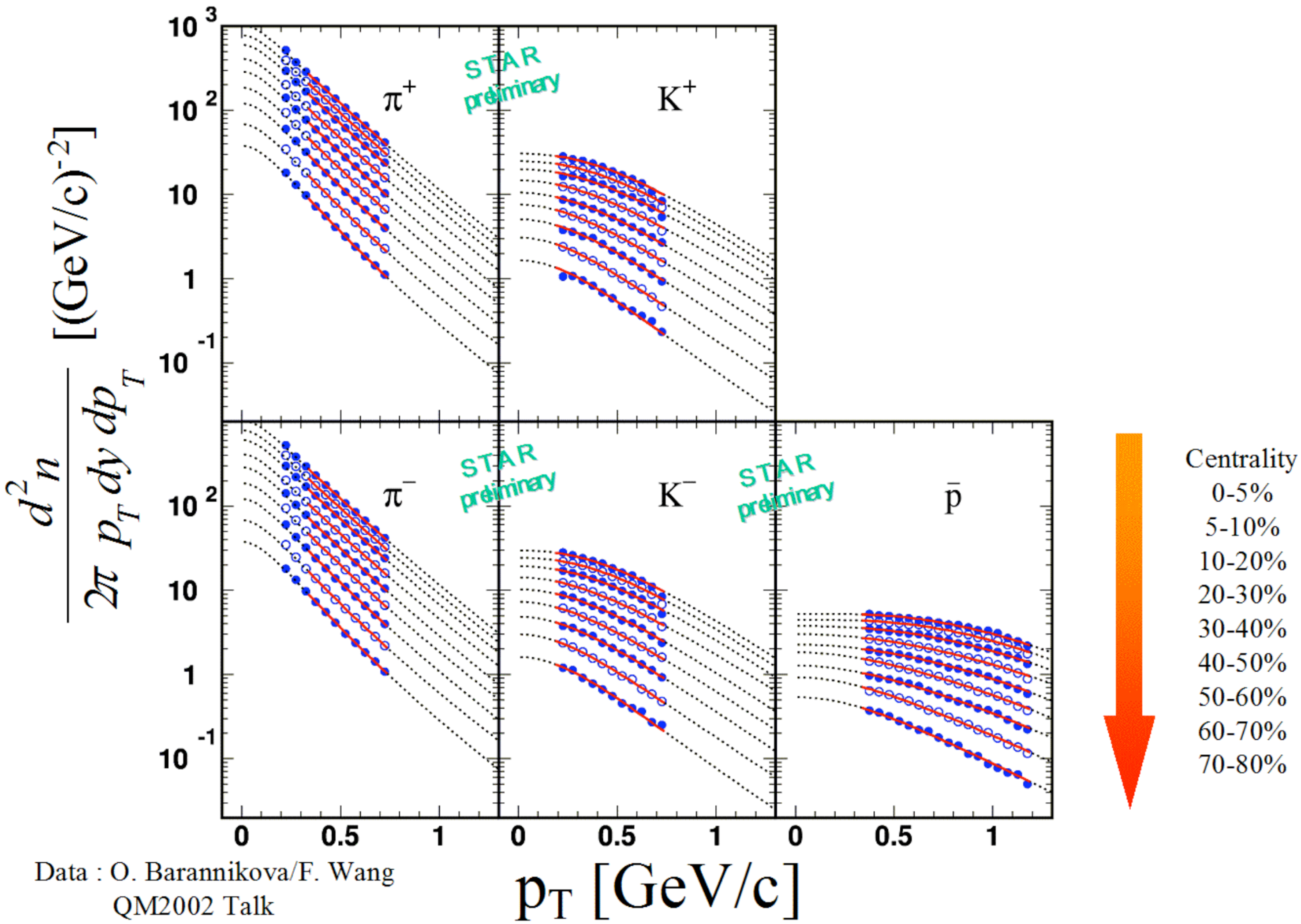


“Thermal Fit” Parameters vs sqrt(s)



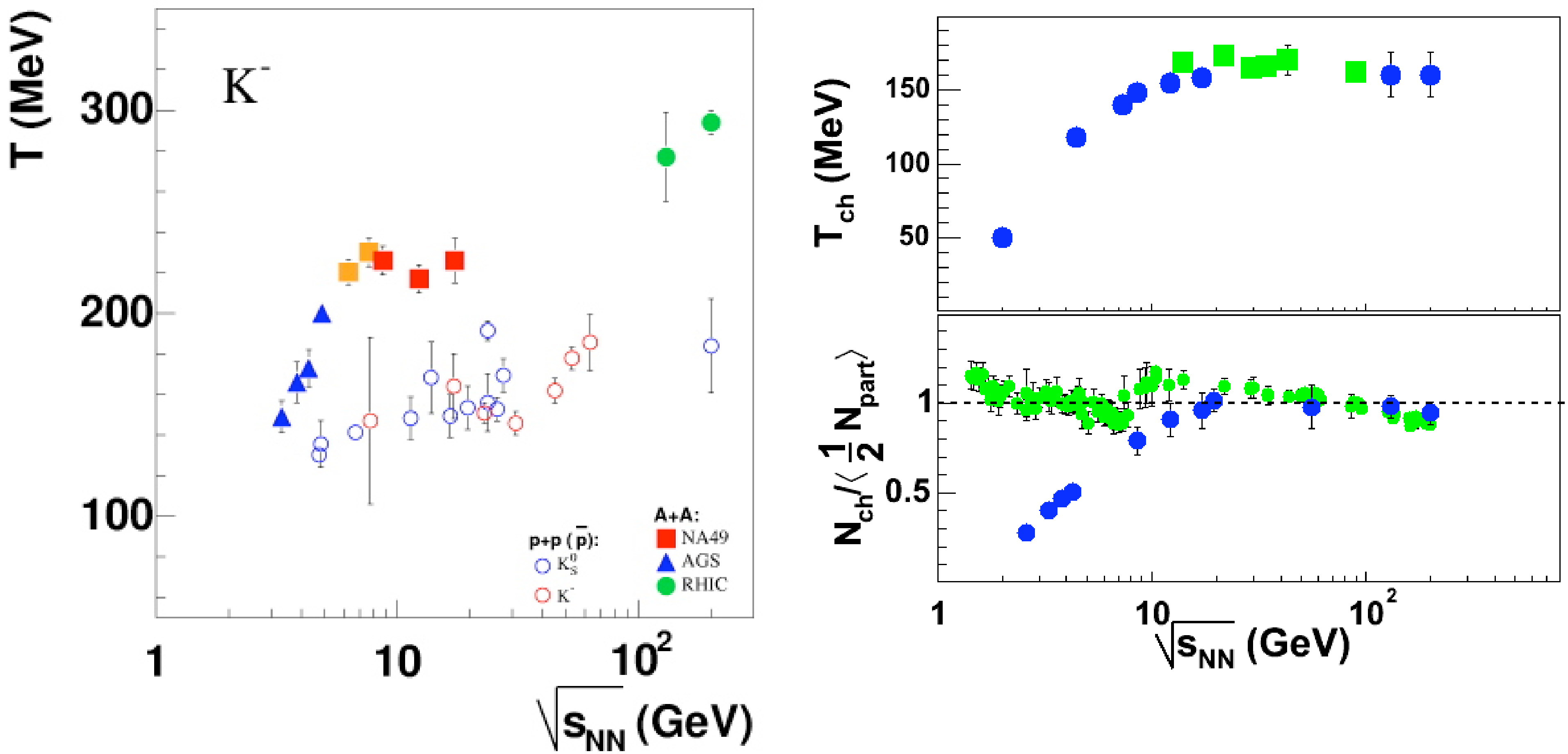


V. Transverse Dynamics



Data : O. Barannikova/F. Wang
QM2002 Talk

Structure in Inverse Slope vs sqrt(s)

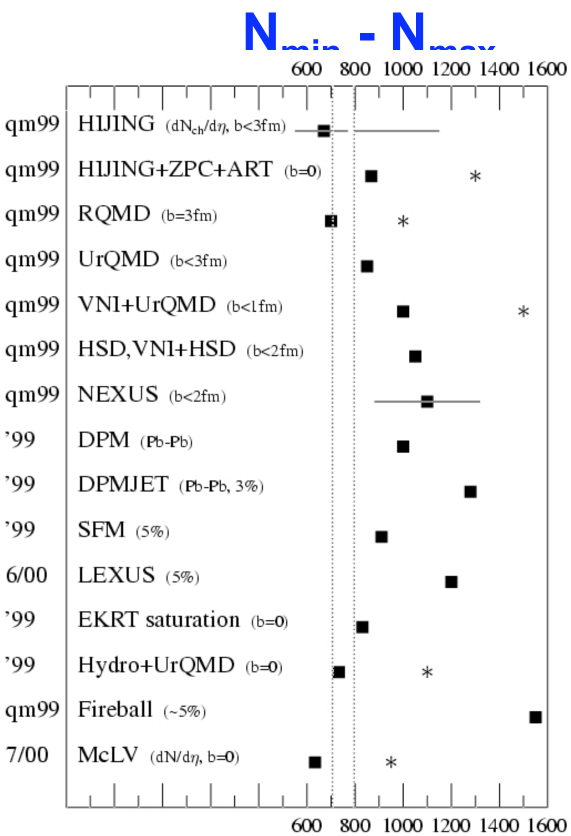


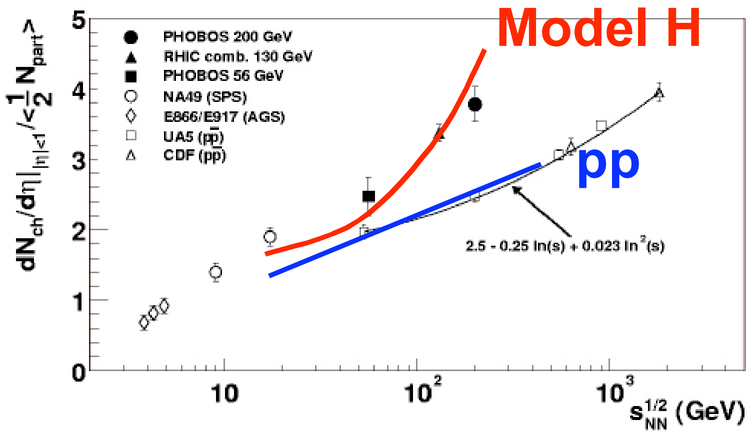
Summary

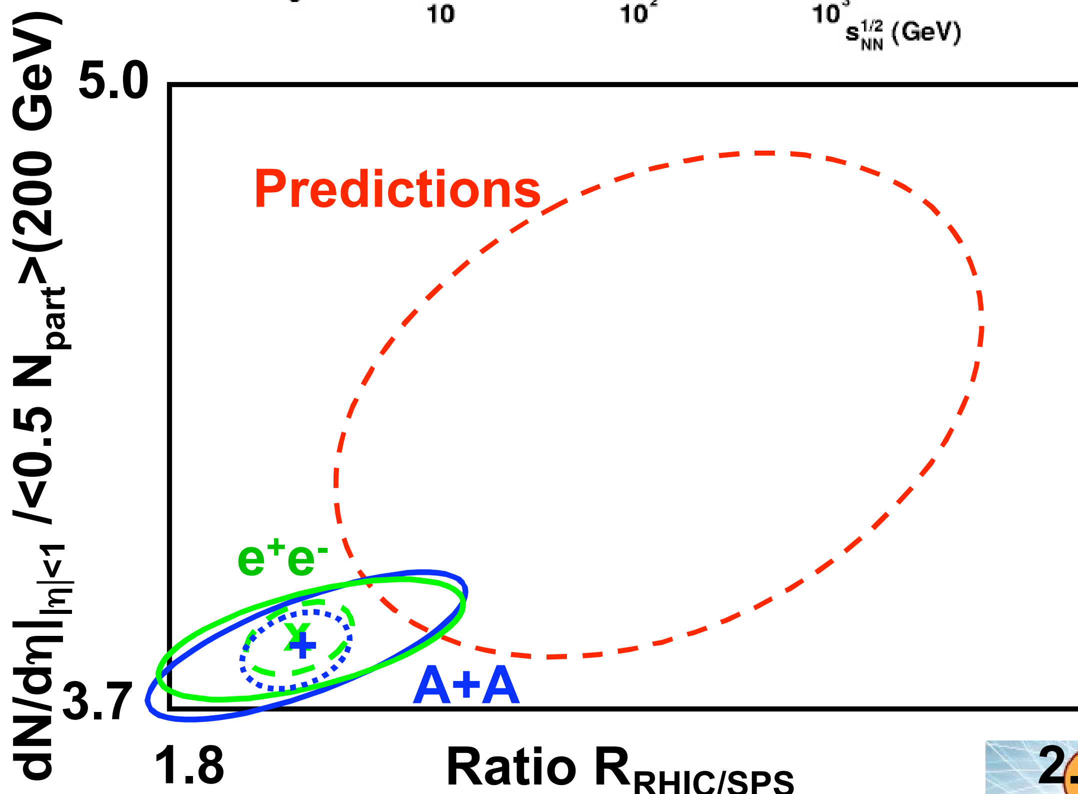
- **Data can indeed by reduced efficiently**
  - We're doing Thermodynamics!
- **Total Multiplicity**
  - Proportional to N_{part}
  - Rises like $s^{1/4}$ from mid-SPS Energy Range
- **π dN/dy Distributions**
  - Single Gaussian with width $\sigma^2 \sim 0.5 \ln(s/4m_p)$
- **Statistical Fits describe Hadron Abundances**
  - Systematic Evolution, Limiting Temperature
- **Correspondence with other 'Hadronic' Systems**
  - p+p, p+A, e^+e^-
- **Max Entropy Evolution from Dense Initial State**
  - **How is the Initial State Prepared?**
  - **Baryon Number Transport?**

Coincidence?

This is a cartoon! (so far)



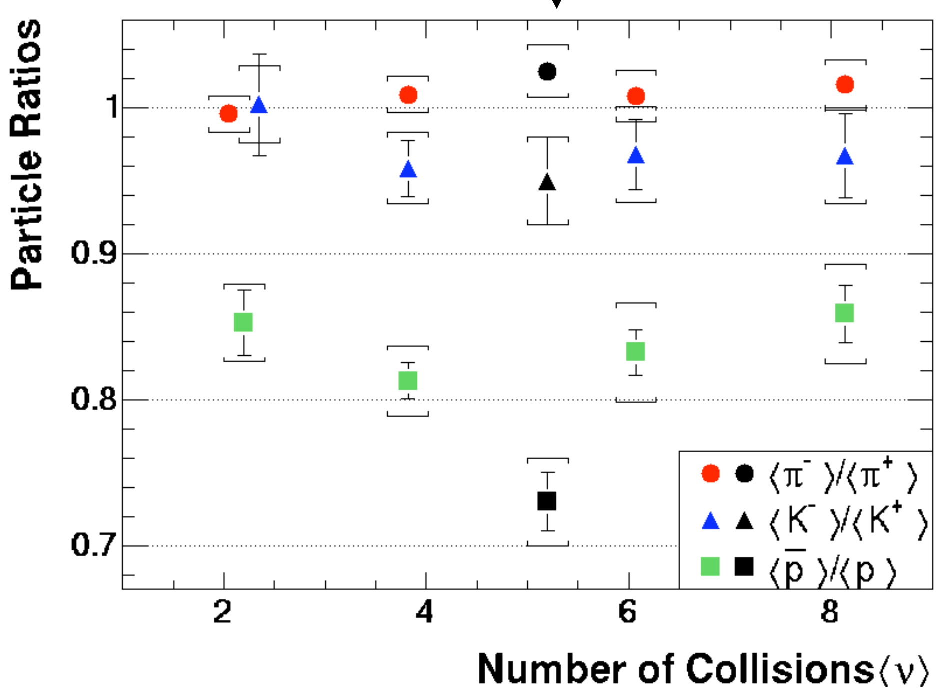




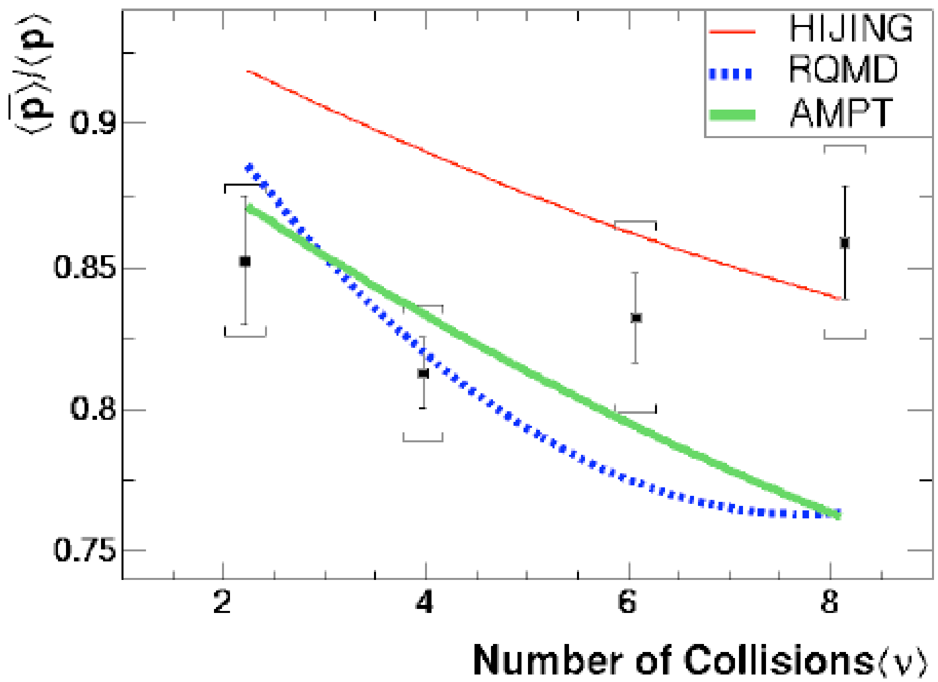
Particle Ratios in d+Au: $\bar{p}/p$ vs Centrality

Au+Au

Phys. Rev. C 67, 021901R (2003)



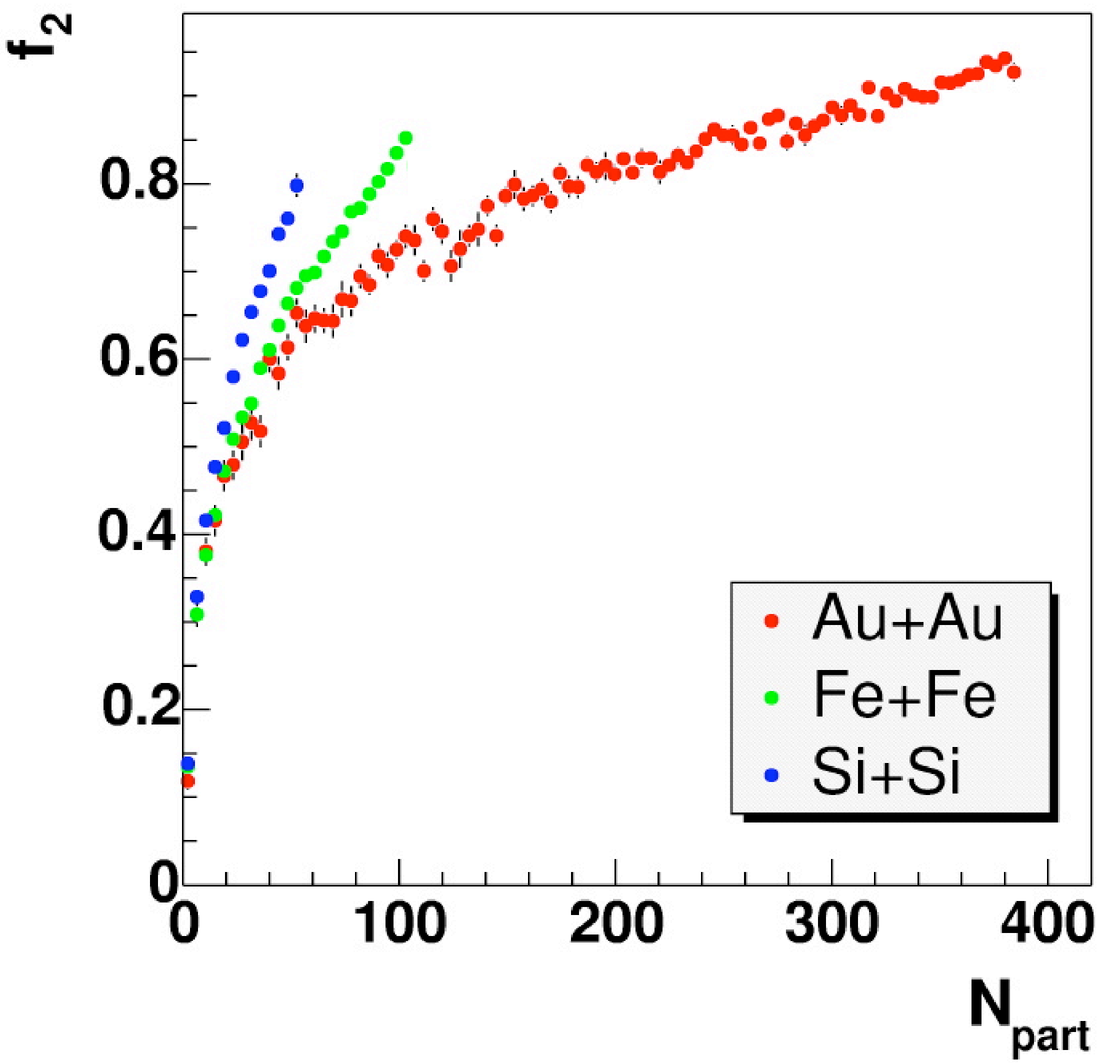
nucl-ex/0309013 - submitted to PRC



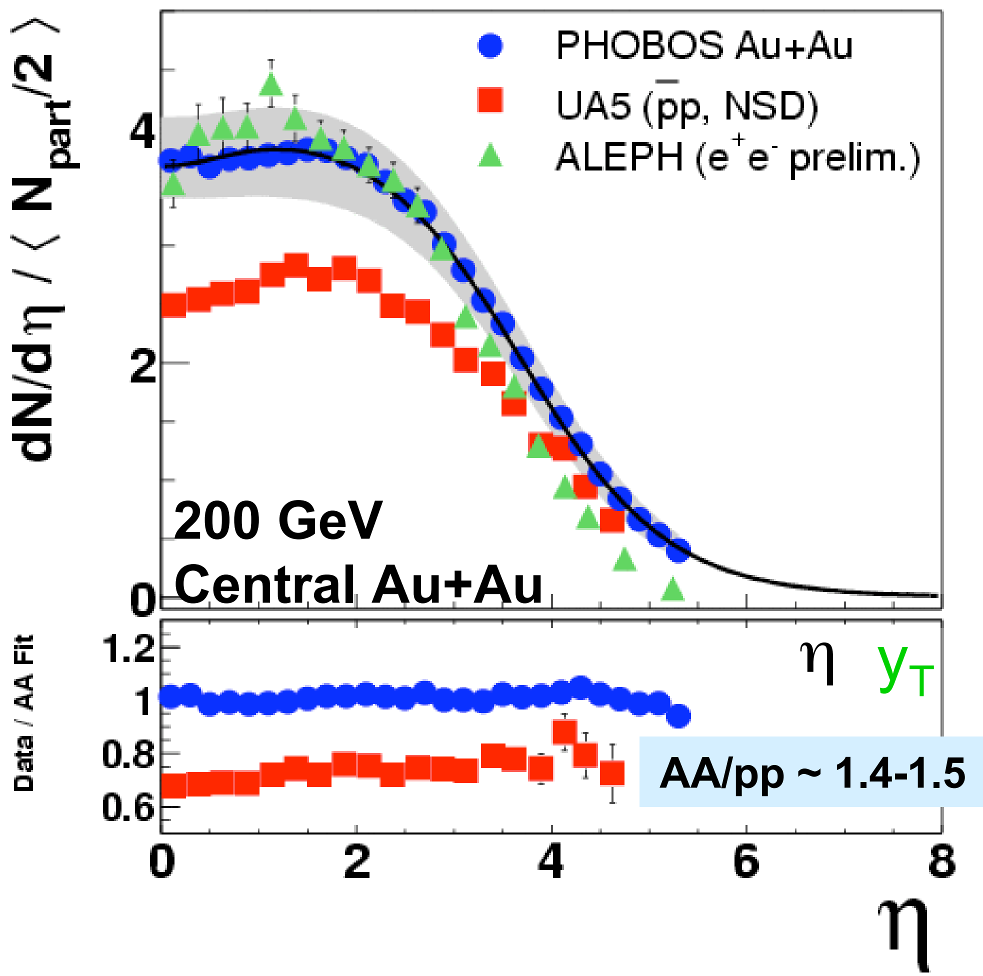
Constant $\bar{p}/p$ ratio vs centrality

Disagreement with expectations/models

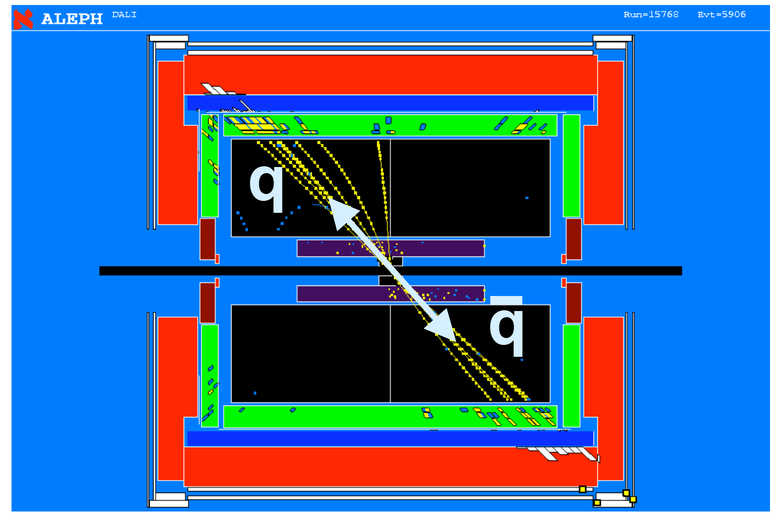
N_{part} scaling?



Rapidity Distributions at 200 GeV



PHOBOS QM'02, Steinberg

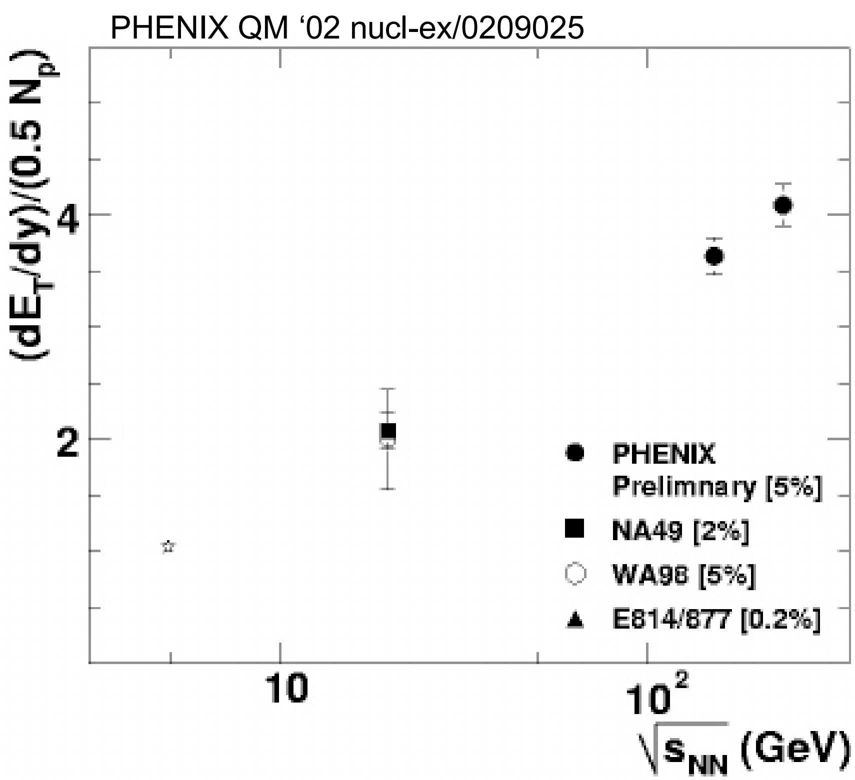


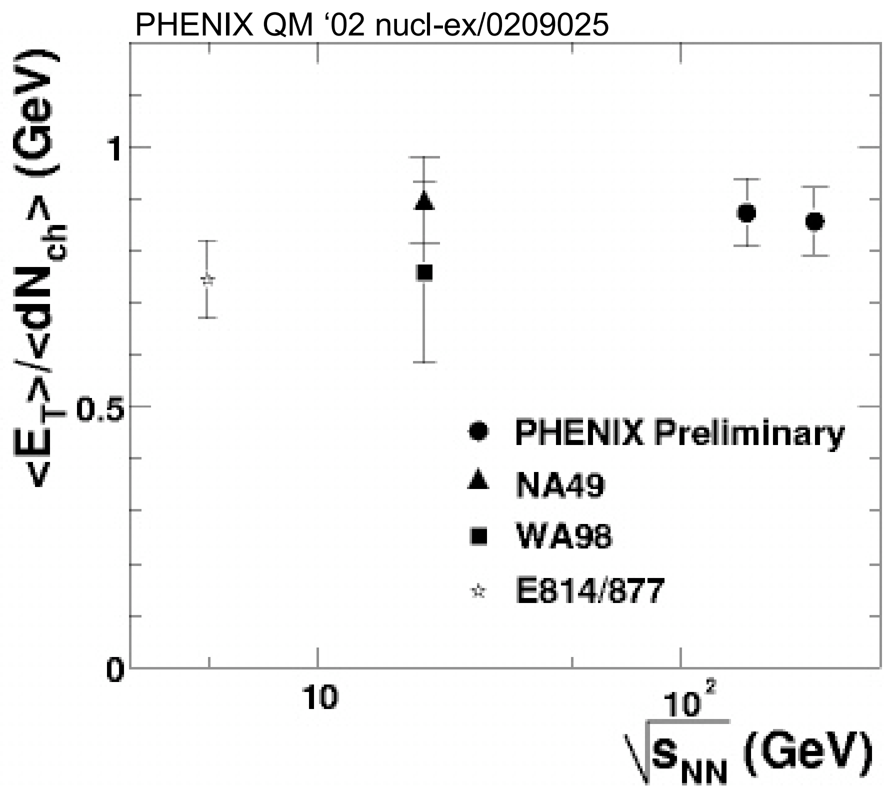
e^+e^- measures dN/dy_T (rapidity relative to "thrust" axis)

Surprising agreement in shape between AA/e^+e^-/pp

Correspondence between perturbative and non-perturbative approaches?

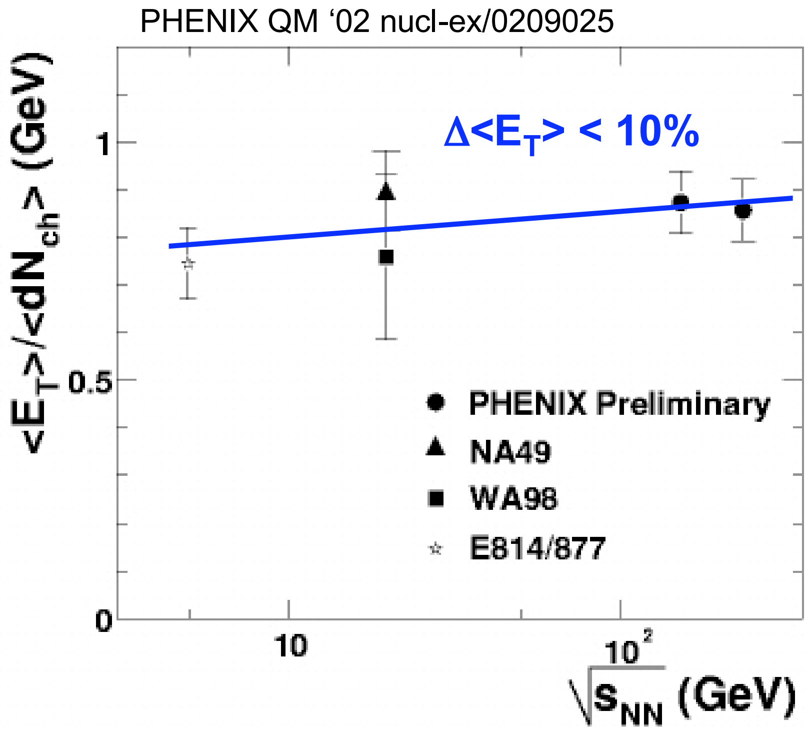
Transverse Energy near η=0

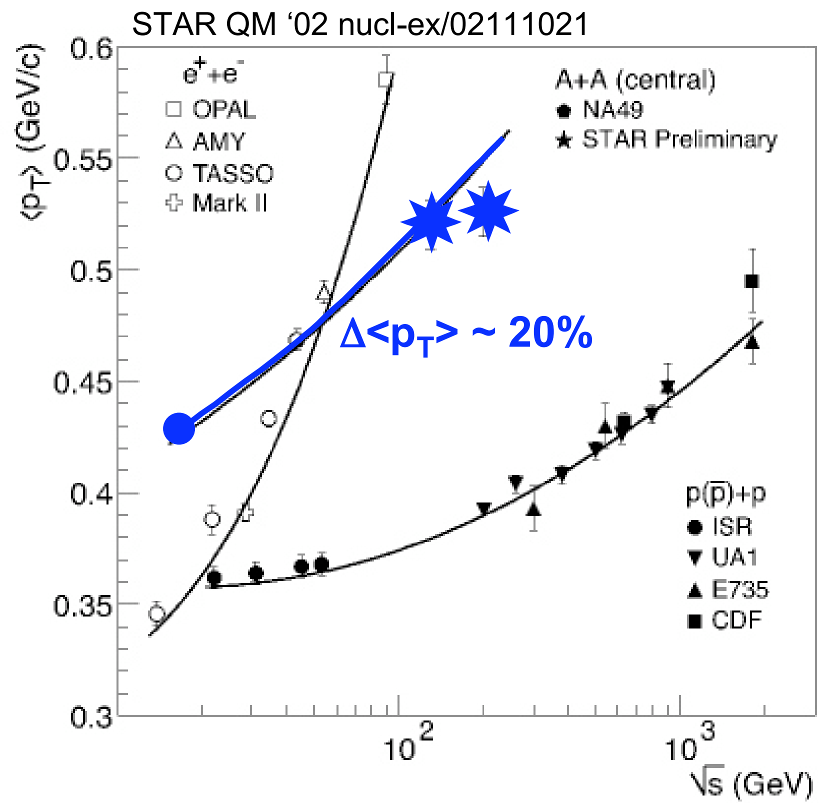




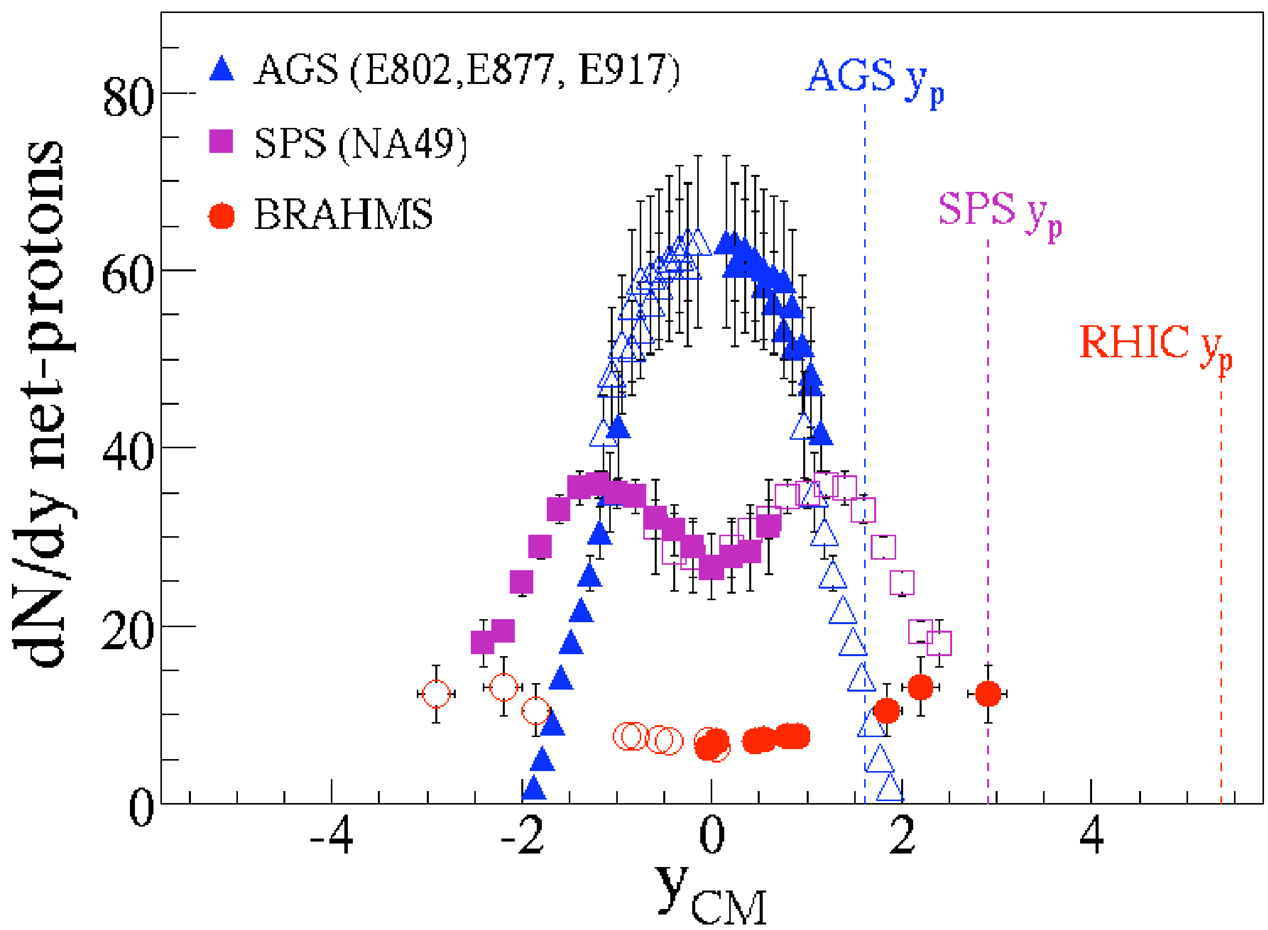
- $dE_T/d\eta$ exhibits smooth rise vs sqrt(s)
- Surprisingly, $\langle E_T \rangle$ per particle at η=0 constant
  - even though p+p spectra get much harder with sqrt(s)

Transverse Energy near η=0



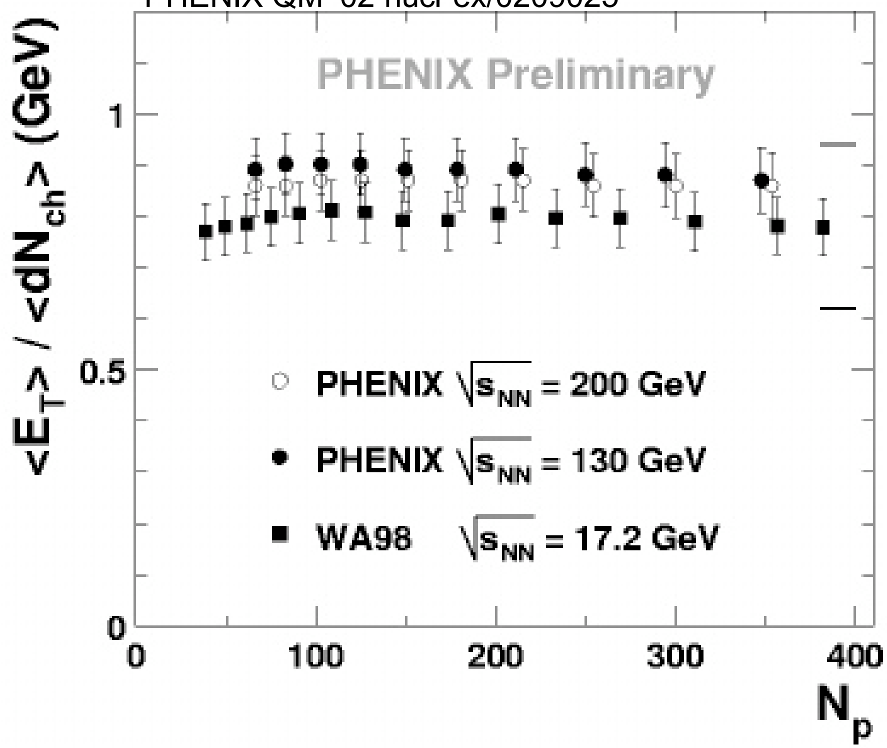


Net Proton dN/dy

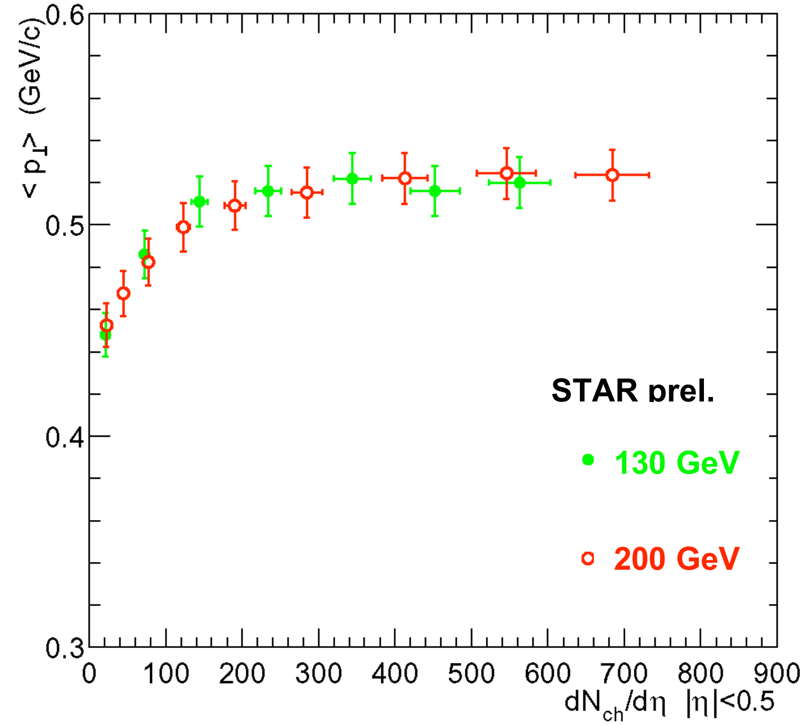


Transverse Energy vs N_{part}

PHENIX QM '02 nucl-ex/0209025



STAR QM '02 nucl-ex/0211021, poster M. Calderon



- $dE_T/d\eta$ and <pT> independent of N_{part} above N_{part} ~50

Boost-invariance?